ization required in any particular gas turbine engine in conjunction with impeller **54** to force the cooling air through blades **42**.

The high-pressure bleed air flows from outlet manifold **48** to heat exchanger **50** by way of outlet conduit **58**. Heat exchanger **50** comprises a casing **60** with an inlet **62** for receiving pressurized bleed air from outlet conduit **58** and an outlet **64** for outputting cooled bleed air to an inlet conduit **66** for return to the core engine. A plurality of straight extruded tubes **68** are arranged inside casing **60** in a generally parallel array, the ends of straight tubes **68** being connected by a plurality of U-shaped tubes **70** to form a serpentine heat exchange circuit.

The internal structure of straight tube **68** is shown in detail in FIG. **2**. Each straight tube **68** has associated therewith a plurality of laterally extending pins or fins **72** distributed at equal intervals along its length. The fins are generally parallel, the parallel surfaces defining the direction of the compressor bleed air flowing therebetween from inlet **62** to outlet **64** of the heat exchanger. Each pinned or finned tube **68** has an axially extending hole **74** extending through the interior thereof via which the fuel from fuel pump **34** flows on its way to fuel control **36**.

In accordance with the first preferred embodiment of the invention, the inlet of the serpentine heat exchange circuit is connected to fuel tank **34** via fuel line **76**; the outlet of the serpentine heat exchange circuit is connected to fuel control **36** via fuel line **78**. The inlet and outlet of the serpentine heat exchange circuit are arranged so that the fuel is in counterflow relationship with the compressor bleed air.

By way of example, the compressor bleed air taken from the fourth stage of the high-pressure compressor has a temperature of about 700° F. and a pressure of about 150 psi. Inside the heat exchanger, that temperature is reduced by the conduction of heat from the compressor bleed air to the external surface of the finned tubes **68**, further conduction of heat from the external surface to the internal surface of finned tubes **68**, and consequent conduction of heat from the internal surface of finned tubes **68** to the fuel. As a result of this heat exchange, the temperature of the bleed air can be reduced by up to 400° F., i.e., to a temperature of 300° F., while the temperature of the fuel is raised by 150° F. As a result, the heat removed from the compressor bleed air is recovered and returned to the engine propulsive cycle, thus improving overall engine performance.

In accordance with a second preferred embodiment of the invention, an inert or nonflammable fluid medium, e.g., water or an antifreeze mixture such as water and glycol, is placed in intermediate heat exchange relationship for facilitating heat transfer from the compressor bleed air to the fuel. This preferred embodiment requires two heat exchangers: the first for the transfer of heat from the compressor bleed air to the intermediate inert or nonflammable fluid and the second for the transfer of heat from the intermediate inert or nonflammable fluid to the fuel. The inert or nonflammable fluid would be pumped by pump **112** through a closed circuit which includes the serpentine heat exchange circuits of both heat exchangers **50** and **50'**, as depicted in FIG. **3**. The advantage of this construction is that in the event of fuel leakage into the second heat exchanger, the fuel leakage will not enter the core engine with the cooling air, which would create a fire hazard.

In accordance with a third preferred embodiment of the invention, fan bypass air is used as a secondary or alternative heat sink. Although the use of fan bypass air as a heat sink provides minimal regenerative benefit, it enables the compressor bleed air to be cooled, with consequent reduction in the metal temperature of the turbine rotor blades, in cases where the fuel cannot serve as a heat sink for the compressor bleed air.

A common feature of all preferred embodiments of the invention is that the cooled bleed air exits the heat exchanger and is piped via inlet conduit **66** to an inlet **80** which communicates with annular inlet manifold **52** by means such as a duct **82**. The inlet manifold **52** circumferentially distributes the cooling air. From inlet manifold **52**, the cooling air is then pumped into an annular cavity **84** between the compressor **18** and tube **85** by way of holes through stub shaft **86** in a well-known manner.

In the regenerative preferred embodiments, the 300° F. cooling air then flows aftward until it reaches an annular chamber **88** located inside the bore **92** of radial outflow impeller **54** and in front of (or to the rear of) turbine disk **40**. The pressure inside chamber **88** is about 135 psi.

As best seen in FIG. **4**, impeller **54** comprises a generally annular disk **94** having a plurality of hollow radial spokes **96** circumferentially distributed on its periphery. Impeller **54** is seated on an arm **98** which extends from the high-pressure turbine disk **40**. As best seen in FIG. **5**, flange **114** of shaft **44**, flange **116** of arm **98** and flange **118** of impeller **54** are secured to disk **120** by bolt **122**.

During rotation of impeller **54**, the cooling air in chamber **88** is centrifuged via radial holes **100**, each of which extends from the bore **92** to the tip of a corresponding spoke **96**. Depending on conditions, impeller **54** will have a pressure ratio of **2** or more. For example, impeller **54** compresses the cooling air to a pressure of about 280 psi and a temperature of about 476° F. The compressed cooling air from impeller **54** then enters the spaces **102** formed between the roots **104** of the rotor blades **106** and the corresponding dovetail slots **108** formed in the turbine disk **40**.

Each rotor blade has a cooling circuit (not shown) of conventional design incorporated therein, which cooling circuit communicates with the corresponding space **102** via one or more inlets formed in the root portion thereof. The rotor blade is then convection and film cooled by the cooling air which flows through the cooling circuit in a well-known manner.

The result of the intercooled cooling air system in accordance with the invention is a considerable reduction in the coolant flow and the coolant parasitic power consumption, as compared to a conventional high-pressure turbine blade cooling air feed system.

In the regenerative preferred embodiments, the heat extracted from the compressor bleed air is not lost to the cycle, but rather is added to the combustion process via the fuel. This adds to the fuel energy input. Thus, an improvement in efficiency and power output can be expected.

The greatest benefit of the invention derives not so much from the reduced coolant airflows, but rather from the ability to considerably raise the turbine entry temperature, while reducing the metal temperature of the high-pressure turbine rotor blades.

In accordance with a further feature of the invention shown in FIG. **1**, at low power states and fuel flow rates below a predetermined threshold, e.g., during cruise